Putting Physics to Work in Next-Generation Automotive and Aerospace Engineering

Sandeep Sovani, Ph.D., ANSYS, Inc., www.ansys.com

The engineering field is founded on fundamental laws of physics which can be explained by governing equations such as Maxwell's equations of electromagnetism and Navier–Stokes equations of fluid motion. However, a profound irony plagues engineering. Formulated more than a century ago, these equations are widely applicable, but one cannot find exact solutions to these equations when applied to practical problems. Theoretical understanding of these equations is incomplete even today, and methods of finding mathematically exact general solutions of these equations do not exist.

Consider the example of creating a new low-drag car design. To evaluate drag force, an aerodynamicist could apply the Navier-Stokes equations to the airspace around the car and mathematically obtain the drag value. However, this is not possible because a mathematical method for solving these equations does not exist. While a method of determining an exact solution for these equations is still unknown, the means of obtaining approximate but highly accurate solutions are available. Modern engineering simulation software running on today's commonplace powerful computers can solve the fundamental governing physical equations. Though these solutions are not mathematically exact, they are accurate enough for practical engineering purposes.

Engineering simulation is the science of solving fundamental physical equations to create a virtual environment that accurately replicates the complexities of a real environment. In a sense, engineering simulation is similar to computer-generated imagery (CGI) used in Hollywood movies with one major difference. Unlike CGI, the virtual environments created in engineering simulation strictly obey the relevant laws of physics where physical effects such as motion, forces, temperatures, etc. accurately replicate reality.

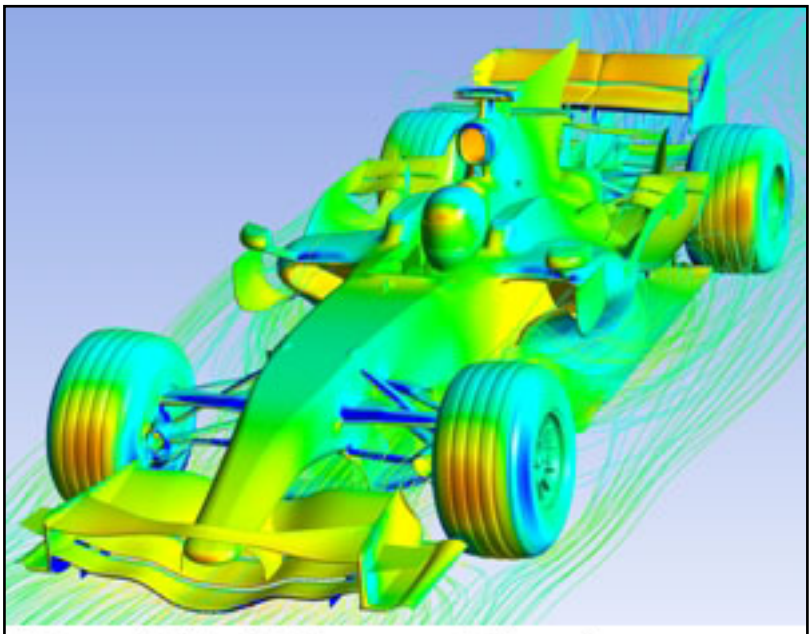

Figure 1. Simulation-generated surface pressure map and airflow pathlines around a Formula 1 race car (Image courtesy of Red Bull Racing)

Development of engineering software began four decades ago, and it has progressed to the point that it can accurately simulate some of the most complex physical phenomena, such as highly turbulent airflow around a Formula 1 race car (Figure 1) or mechanical stresses on an aircraft fuselage that result from cabin pressure (Figure 2).

The automotive and aerospace industries are experiencing their own kind of “turbulence.” Governments and consumers are demanding less pollution, safer vehicles and ever-increasing innovation; the corporate bottom line goes even further, mandating efficient processes, lower costs and winning product differentiation without risk. One false move can set back an entire brand.

Getting It Right the First Time

The most successful companies are differentiating themselves by employing modern simulation technology in the earliest stages of product design, thereby reducing development cycles and lowering costs. The traditional build-and-test method relies on creating prototypes, obtaining appropriate testing equipment and conducting tests, which can be laborious, expensive and time consuming. With simulation, engineers can study and test a product’s behavior with ease, speed and thoroughness.

For instance, automotive engineers routinely use virtual wind-tunnels to study the aerodynamics of cars. Engineering teams create a computer model of the car and place it within a simulation software program. When the airflow is “turned on,” virtual air flows around the virtual car almost exactly as it would if the real car were in a physical wind tunnel. (Figure 1) The development team can study the air flow using techniques such as cut-planes, colored smoke lines and others to thoroughly understand the flow structure — and gain ideas about how to reduce aerodynamic drag by changing the car’s shape. The simulation software can also apply smart

algorithms to indicate areas that could be altered to reduce drag. Engineers in the aerospace industry use similar processes. Since the basis of flight is aerodynamics, simulation results must be highly accurate in aerospace engineering.

Simulation provides two key advantages compared to physical prototyping and lab testing. First, virtual testing is highly cost and time effective. Building prototypes, obtaining appropriate testing equipment and conducting tests is significantly more laborious, expensive and time consuming than simply creating a computer model and running it in a simulated virtual environment. The process is particularly advantageous when hundreds or thousands of design options must be evaluated to find an optimal approach. Secondly, simulation provides in-depth, extremely valuable insight into product behavior, which is difficult to obtain via

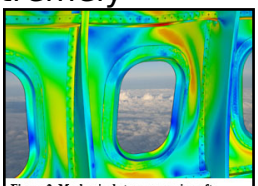

Figure 2. Mechanical stresses on aircraft fuselage interior resulting from cabin pressure (Image courtesy CADFEM and Airbus Deutschland GmbH)

prototyping and testing. For example, simulation that analyzes car aerodynamics can provide a detailed pressure map of the vehicle's entire surface (Figure 1). Flow velocity can be mapped at any cross-section of airspace around the vehicle. Such detailed insight empowers engineers to quickly identify areas where improvements can be made. In contrast, physical testing would require placing millions of tiny sensors all over and around the car to obtain similar data.

Hybrid Electric Vehicle Development Hinges on Simulation Software

The recent economic upheaval has forced the automotive industry to proactively address climate concerns, petroleum shortage issues and government regulations. As a result, vehicle manufacturers and suppliers are developing dramatic new technologies, such as hybrid and electric vehicles (HEV), which are mostly based on fuel efficiency. Simulation is the only viable way to design such vehicles in the short time frame that consumers, governments and markets demand.

For example, engineers strive to reduce a HEV's overall weight, since a lighter car uses less energy in start-and-stop city driving. A large number of parameters come into play: shape, size and material — of virtually all vehicle components. Excess material must be removed but not at the expense of performance.

Furthermore, HEV components and subsystems require tight optimization to extract the highest efficiency. For instance, there are hundreds of thousands of design candidates for the magnetics of electric traction motors alone. Which is the optimum one? No engineering design department can create that many prototypes and perform physical testing in the race for a better car; high-end simulation is the only trustworthy alternative.

The most complex issue to this industry is the electric powertrain, a system that has no forerunner. In full electric vehicles, this powertrain completely replaces the traditional IC engine and mechanical transmission-based powertrain. In hybrids, both powertrains exist side by side. Its main components are the battery, power electronics and traction motor, along with advanced electronic controls for all these

parts. Weight reduction measures are particularly important in hybrid vehicles since the electric powertrain adds enormous weight.

Like the vehicle itself, engineering design tools must evolve to incorporate new paradigms: multiphysics, integrated simulation and automated design exploration.

Figure 3. There are hundreds of simulation software applications in automotive engineering. A few samples are shown here.

Unlike other automotive mechanical components (brackets, axles), electric powertrain components are highly multiphysical in nature. There is tight interplay between multiple physical aspects, such as electrical, magnetic, fluid, thermal and structural. Past-generation simulation software typically handled only one physical attribute at a time, such as fluid flow or structural dynamics, whereas next-generation software performs multiphysics simulation.

Furthermore, electric powertrain components are, by nature, highly interdependent. For instance, the electric traction motor in these vehicles will not even turn unless it

is carefully matched with the power electronics. As a result, electric powertrain components must be co-developed with the overall electric powertrain system. Next-generation simulation software must be able to perform “integrated simulation,” or seamlessly interconnected co-simulation of components and system.

Finally, electric powertrain components require a high degree of optimization to reach ambitious fuel efficiency targets, requiring the study of a large number of design alternatives. Automated design optimization tools are needed, such as design explorer algorithms, high-performance computing capabilities and distributed solve options.

Some of the leading simulation packages available today embrace these next-generation simulation paradigms and are being used heavily by hybrid and electric vehicle manufacturers.

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